Lake Creation on Cutaway Peatlands

A report based on the PhD research of

Tara Higgins

Under the supervision of

Prof. Emer Colleran

Environmental Microbiology Research Unit,
Department of Microbiology,
National University of Ireland, Galway, Ireland.

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By 2030, over 80,000 hectares of industrially harvested peatland will be redundant in Ireland. Lake creation represents a major post-harvesting land-use option for Bord na Móna, which envisages that up to 20,000 hectares of cutaway peatland will be rehabilitated as conservation and amenity water bodies. A further 20,000 ha of cutaway surrounding the lakes will be allowed to spontaneously recolonise, forming an extensive semi-natural wilderness. This represents one of the largest habitat creation opportunities to emerge in Europe in modern times.

This study focused on four experimental cutaway lakes, which were monitored between 2001 and 2004 for various water quality parameters. The lakes were constructed using three alternative strategies, involving varying levels of peat removal, hydrological manipulation and revegetation. This research aimed to elucidate the key factors influencing water quality in these artificial, pioneering lake ecosystems, and to develop recommendations that will enable future cutaway lakes to be designed and managed for optimal water quality, in turn maximising their biodiversity and conservation potential.

Results indicated that the physico-chemical environment in cutaway lakes is determined primarily by the nature of the sediments and the hydrological regime. These two factors relate directly to the lake creation strategy used. Lakes containing minerotrophic fen peats and exposed inorganic sediments, with introduced hardwater inflows, had alkaline pH values, were base-rich and contained low to moderate levels of colour. In marked contrast, the study lake created by simple flooding (Strategy 3), which was underlain exclusively by peat and received water inputs only from precipitation and associated runoff, was strongly acidic, base poor and highly coloured.

Nutrient levels in cutaway lakes were strongly influenced by catchment land-uses. Lakes with inflows draining agricultural land exhibited a marked seasonal trend in nitrogen levels, reflecting nitrate runoff from agricultural land in winter. The study lake created using Strategy 3 became highly eutrophic during the 3-year study, in response to phosphate leaching from nearby commercial forestry plantations. Such lakes are highly vulnerable to nutrient runoff and the coincident development of phytoplankton blooms due to a number of reasons: the high propensity of unconsolidated, bare cutaways to runoff and erosion; the paucity of recolonist revegetation to sequester nutrients; weak top-down control by zooplankton grazing; and, a lack of iron and carbonate buffering mechanisms at such sites.

This research clearly highlighted the benefits of revegetating cutaway peatland designated for lake creation. Higher plants perform several valuable functions, by increasing sediment stability, reducing nutrient availabilities and promoting foodweb development through providing habitats, refugia and food for invertebrates. The desirability of maximising the physical habitat diversity of cutaway lakes and maintaining an active hydrological flow-through were also highlighted in this study, as was the need for integrated planning and long-term monitoring of cutaway lakes, to ensure that the maximum biodiversity and conservation value of these resources are realised.
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1 Introduction to Cutaway Peatlands

By 2030, there will be over 80,000 hectares of cutaway peatland in Ireland. Bord na Móna proposes designating over half of this for non-commercial conservation and amenity uses, including lake creation. This represents one of the largest wildlife habitat creation opportunities to emerge in Europe in modern times.

Global Distribution of Peatlands

Variously referred to worldwide as bogs, mires, moors and fens, peatlands are wetland ecosystems in which the substratum is composed largely or entirely of organic matter. Peat forms under waterlogged conditions when organic matter is produced by plants and deposited at a faster rate than it is decomposed. The Irish word for peatlands, bog, is derived from the Gaelic bogach, meaning soft ground. The global distribution of peatlands is very closely associated with climatic conditions. Peatlands are found in wet climatic regimes characterised by an annual water surplus. After Finland, Ireland has the highest proportion of peat cover of any European country, with 1.3 million ha or 17% of total land cover composed of peatland (Fig. 1).

Raised Bog Formation

The primary influence which determined the present form of the Irish landscape was the Ice Age. After the retreat of the ice sheets in approximately 10,000 BC, the Irish Midlands were dotted with shallow, mineral-rich lakes. The post-glacial lakes became densely colonised by stonewort plants (Chara spp.), which assimilated dissolved inorganic carbon from the water column and precipitated it externally as crystalline encrustations of calcite. The seasonal die back of charophytes resulted in an annual deposition of lime on the lake bottom (Fig. 2a). Over many centuries, this cycle led to the build up of a deep layer of chalk-like marl, sometimes greater than a metre in thickness. As the lakes became shallower, vegetation encroached from the shores. The lakes gradually developed into swamps dominated by reeds (Phragmites spp.), reedmaces (Typha spp.) and rushes (Juncus spp.). As the reeds died, their remains only partially decayed under the prevailing anoxic conditions. The steady accumulation of reed swamp peat eventually led to the complete infilling, or terrestrialisation, of the lake to form a fen (Fig. 2b). In turn, the fen vegetation, comprising grasses (Molinia spp.), sedges (Carex spp.) and mosses (Sphagnum spp.), died off, depositing a layer of black fen peat (Fig. 2c).

Figure 1. The proportion of land area covered by peatland in various countries worldwide

There are two main types of peatland in Ireland, raised bog and blanket bog. Raised bogs are concentrated in the central plain, under moderate rainfall of 700-1,000 mm per year, while blanket bogs are found chiefly in the west of Ireland and on mountaintops nationwide, where annual rainfall levels are typically >1,250 mm. Raised bogs have formed a distinctive and characteristic feature of the Irish Midlands since their formation over 4,000 years ago.
As the peat level rose, the influence of calcareous groundwater declined and precipitation became the main irrigation source. Conditions became increasingly acidic and nutrient-poor and *Sphagnum* mosses replaced the fen vegetation (Fig. 2d). This marked the transition from minerotrophic fen (alkaline, mineral rich) to ombrotrophic bog (acidic, mineral poor). With their sponge-like structure, *Sphagnum* mosses increased water-logging and created a perched water table. Eventually, the raised bog system became completely hydrologically isolated from the surrounding landscape.

In time, the bogs encroached onto higher, dry areas which had previously supported rich woodlands of oak, pine and yew (Fig. 2e). As waterlogging increased, the trees died and became fossilised in the accumulating anoxic peat. The hillocks and hummocks of the original post-glacial landscape were progressively levelled out under a peat cloak, which grew at a rate of about 1 cm every 20-25 years. The end result was a climax ecosystem consisting of a dome-shaped layer of *Sphagnum* peat raised 12-15 m above the surrounding landscape, prompting the name 'raised bog' (Fig. 2f).

![Plate 1. Sphagnum Bog](image)

![Figure 2(a-f) Stages in the formation of a raised bog over a 10,000-year period](image)

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The History of Peat Harvesting

The growth of raised bogs in Ireland continued unaffected by human activity for many centuries. The bogs were generally avoided by humans who regarded them as vast, unproductive wastelands. However, the clear felling of the forests for agricultural and military purposes during the 17th and 18th centuries, and the subsequent demand for a new fuel source for the expanding population, encouraged more widespread, systematic peat harvesting. \textit{Sphagnum} peat was hand-cut from the bogs in vertical sods using an implement called a \textit{sleán}. By the time Bord na Móna was established in the 20th century, roughly half of the Midland raised bogs had been cutover by hand.

The move towards mechanising peat cutting began in the 19th century. This was influenced by the development of the Grand Canal, which enabled the transportation of peat products to Dublin for sale. Recognising the importance of peat for Ireland’s economic development, in 1936 the Free State government established the Turf Development Board, which acquired vast acreages of Midland raised bog. The advent of World War Two and the subsequent Fuel Emergency Plan gave great impetus to these developments. A new statutory body, Bord na Móna, was established in 1946, with the objective of placing a greater focus on electricity generation at peat-powered stations. In a series of large-scale acquisition programmes between 1946 and 1983, the company acquired ownership of 86,000 ha of peatland. During the 1950s, Bord na Móna changed the focus of its operations from sod peat production to a Russian system of peat milling referred to as the Peko system. In 1957, a new 80 megawatt power station at Ferbane in Co. Offaly became the first plant to produce electricity from milled peat outside of the Soviet Union.

Peat harvesting is a finite operation, which takes 45-55 years. ‘Cutaway’ describes a worked-out bog in which all or most of the peat reserve has been mechanically removed. The end to peat harvesting does not occur uniformly; rather, sections of a bog become worked-out in stages, until eventually the entire area is deemed cutaway. Production ceases for various reasons e.g. fossil tree stumps impede milling; exposed white marl contaminates the peat; sub-surface ridges of esker gravels or bedrock are reached; extraction goes below the permanent water-table so that costly pumped drainage is required to maintain a lowered water table. These factors contribute to marked differences in residual peat depths, subsoil characteristics and drainage properties. Such discrepancies are major determinants of the post-harvesting uses of redundant cutaway peatlands.
Post-Harvesting Uses of Cutaways

Bord na Móna began investigating after-uses of cutaway peatlands in the 1950s. Commercial applications were the focus of early attention and it was envisaged that a vast new productive land area, equivalent in size to Co. Louth, would become available for a variety of economic uses. Together with An Foras Talúntas and Collette Teoranta, research was conducted to explore the potential for rehabilitating cutaways for grassland, livestock rearing, cultivation of vegetable and cereal crops, coniferous forestry and short-rotation hardwood forestry for energy production.

A number of definitive conclusions were reached regarding the post-harvesting options for industrial cutaway peatlands. Growing biomass and arable crops was initially proven to be uneconomical or technically infeasible. Problems encountered with forestry included susceptibility to late frosts, competition with invading natural species, waterlogging, instability of peat substrata, nutrient deficiencies and damage by pests, such as hares. Ongoing research aims to establish suitable sylvicultural practices for cutaway peatland46. Similar difficulties were encountered with agricultural grassland establishment. Grassland creation was most successful where <1 m of fen peat remained. Here, deep ploughing radically improved drainage and mixing by shattering the iron pan at the fen peat-mineral subsoil junction. By 1999, high quality grassland had been established on 1,200 ha of cutaway peatland. This was sold to 18 local farmers in 23 sale lots, with subsequent socio-economic benefits by increasing local farms to viably-sized units.

In recent years, a third major post-harvesting use for cutaway peatland in Ireland has emerged. Bord na Móna has shifted the focus of its attention away from commercial forestry and agricultural applications towards wildlife conservation, amenity and tourism after-uses. This new approach to cutaway peatland rehabilitation is exemplified by the pioneering Lough Boora Parklands project.

Lough Boora Parklands Project

During the 1970s and 1980s, large expanses of cutaway peatland in the Irish Midlands which were deemed inappropriate for commercial forestry or grassland rehabilitation were effectively abandoned. These areas developed spontaneously into a diverse range of semi-natural wilderness habitats, ranging from stands of open water to intermediate wetland and swamp areas, to drier areas of natural grassland, scrub and woodland. At Boora in mid-west Co. Offaly, local interest in maximising the community benefit of these areas steadily grew. In 1994, the newly formed Boora Enterprise Group published a detailed land-use plan for 2,200 ha of cutaway within the Boora Bog complex. Called the Lough Boora Parklands, the plan blended existing commercial developments into new land-uses which had, for the first time, a tourism, amenity, conservation and educational focus. The Group envisaged that the direct and indirect employment to emerge from these developments would help replace local jobs in the declining peat industry.

The Parklands, to date, incorporate 6 angling lakes, collectively covering an area of 40 ha, including Loch an Docharis which was designed specifically for disabled anglers.

There are 13 shallow conservation lakes, encompassing 430 ha. Over 1,500 ha of cutaway has been developed as commercial forestry and over 800 ha as agricultural grassland. The Parklands also contain 500 ha of naturally regenerating grassland and scrub areas, while the remains of a mesolithic settlement have been carefully preserved. Facilities such as walkways, information points, car parks, bird hides and picnic tables have been provided with the aid of EU funding. A canoeing course has been developed and the Parklands are also used for clay pigeon shooting and model aircraft flying. Lough Boora Parklands are now recognised as the National Centre of Cutaway Bog Rehabilitation in Ireland.

The Lough Boora Parklands project is being viewed as a blueprint for the future large-scale development of integrated land-uses on cutaway peatland. Bord na Móna now envisions that at least 50% of all future cutaway peatland, totalling 40,000 ha, will be assigned for amenity and conservation uses. This will include 20,000 ha of shallow lakes and wetlands. The scale of the proposals is exceptional, representing one of the largest wildlife habitat creation opportunities to emerge in Ireland, or indeed Europe, in modern times. A number of factors have contributed towards the increasing designation of cutaway peatland for conservation and amenity after-uses, including lake creation. These include a statutory obligation on Bord na Móna, under its IPC licence, to develop a comprehensive rehabilitation plan for all of its cutaways; the numerous practical and technical difficulties associated with cutaway rehabilitation for forestry and grassland; a Europe-wide shift away from intensive agricultural practices in response to CAP reforms and the emergence of increasing areas of cutaway from bogs under costly pumped drainage. A factor of increasing importance is the growing awareness at international, national, local and managerial level of the importance of wildlife preservation areas and the significant role that wetlands, in particular, can play in enhancing the national biodiversity resource.
Ecological Value of Cutaway Peatlands

The considerable ecological importance of cutaway peatland stems from the wide diversity of habitats it supports in close proximity to one another. These include bog and fen remnants, wetland areas, stands of open water, dry grassland meadows, reedbeds, scrub patches and woodlands, all of which exhibit great variation in terms of their degree of water-logging, pH, mineral and nutrient status.

The last remaining population of wild Grey Partridge (*Perdix perdix*) in Ireland was recorded in the Lough Boora Parklands in 1999 and a site within the Parklands is now the focus of the Irish Grey Partridge Conservation Project. Other endangered bird species within the Lough Boora Parklands include Whooper swans (*Cygnus Cygnus*), Hen Harriers (*Circus cyaneus*), Merlins (*Falco columbarius*), Nightjar (*Caprimulgus europaeus*) and Lapwing (*Vanellus vanellus*). A 153 ha cutaway area at Turraun has been designated a National Nature Reserve in recognition of its diverse bird life.

At least 265 species of vascular plants have recolonised the Lough Boora Parklands and it is likely that new species are immigrating continually. Notable species include Autumn Gentian (*Gentianella amarella*), Field Gentian (*Gentianella campestris*), Goat’s Beard (*Tragopogon pratensis*) and Heath Dog-violet (*Viola canina*). Several species of insectivorous Bladderwort (*Utricularia* spp.) and Sundew (*Drosera* spp.) are also present in the Parklands, as well as 39 species of lichen and 92 species of butterfly and moths, including the endangered Marsh Fritillary (*Euphydryas aurinia*).
Cutaway peatlands exhibit enormous variability and instability in terms of their hydrology, the type, depth and drainage characteristics of the remaining peat and the nature and permeability of the underlying inorganic soils. Understanding this variability is an essential precursor to planning any future land uses, including the option of lake creation.

**Profile of an Undisturbed Raised Bog**

An intact raised bog consists of a dome-shaped mound of ombrotrophic *Sphagnum* peat up to 12 m deep, which has two distinct peat horizons (Fig. 3). The upper, loosely structured, permeable horizon, containing the living plants, is referred to as the acrotelm. It varies in depth between 10-50 cm and is the actively peat-forming part of the raised bog. The water storage properties of the *Sphagnum* mosses that form the acrotelm stabilise the water table and maintain it at, or close to, the surface of the bog.

The layer of dead ombrotrophic *Sphagnum* peat underlying the acrotelm is called the catotelm. Situated below the water table, the catotelm is permanently saturated. The type of peat comprising the catotelm is classified according to the type of plant matter from which it originated. These plant materials typically consist of varying layers of *Sphagnum* moss peat, *Phragmites* reedswamp peat and woody fen peat containing fossil tree remains (Fig. 4).

**Profile of a Cutaway Peatland**

Industrially milled cutaway bogs are entirely different from intact raised bogs (Fig. 5). They consist of vast, bare and relatively uniform surfaces interspersed by deep drainage channels. The acrotelm and its vegetation has been removed, which means that the bog surface lacks microtopography. Usually, much of the catotelm peat deposit has also been extracted. Thus, what remains after peat production has stopped are varying depths of fen peats and, in some places, exposed inorganic subsoils. The new surface in a cutaway bog represents, in a broad sense, the Quaternary landscape during the early stages of raised bog formation about 10,000 years ago.

The depth of peat remaining after the cessation of harvesting activities at a cutaway site varies greatly due to the strongly undulating nature of the subsurface topography.

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An area of cutaway overlying a depression in the sub-peat surface can have a peat depth of greater than 2m while, in nearby areas, the mineral soil breaks through a shallow peat cover. The upper centimetres of peat in a cutaway bog are usually very loose, resulting from a combination of the industrial harrowing processes, wind and water erosion, the action of frost and the oxidation and renewed decomposition of the peat. Below the loose surface layer, the remaining bulk of the fen peat deposit is highly compressed, due to thousands of years of compaction under several meters of peat and, in recent times, drainage for peat harvesting and the repeated passage of the milling machinery.

The sub-peat mineral soils are described as "relict" soils. They comprise alluvial soils such as gravels, sands, silts and silty clays, as well as lake deposits of white calcium-rich shell marl (Plate 6) and chalk muds. Saturated beneath the overlying bog and completely isolated from weathering influences since the end of the last ice age, these soils are anaerobic, lack a typical soil profile and contain little or no organic matter. These soils are hence very nutrient poor. Any iron present is in the ferrous form, which imparts a characteristic grey/blue colour.

A strong correlation exists between the sub-peat mineral soil type and the nature of the peat overlying it. The limestone boulder till soils that formed the original post-glacial hummocks tend to be more weathered, since they remained exposed to the elements for a longer time. They generally underlie relatively free-draining woody fen peat. Where the sub-surface contours form a natural hollow, the peat type is usually poorly-drained reedswamp peat overlying impermeable lake marls and unweathered blue silty clays.
Cutaway Lake Creation Strategies

Different approaches have been adopted by Bord na Móna when constructing lakes on cutaway peatlands. Decisions are based on factors such as a site’s topography and drainage characteristics, the availability and quality of supplementary water sources, the depth and type of residual peat, the nature and degree of exposure of underlying mineral substrata and the purpose for which the waterbody is intended.

There are also practical considerations, such as accessibility, cost and implications for ongoing management. As with most cutaway rehabilitation projects, lake creation projects usually involve a trade-off between desirability and feasibility. While it is impossible to propose a universal recipe for cutaway lake creation because of the high degree of site specificity involved, it is possible to distinguish 3 broad approaches (Fig. 6, overleaf).

- **Strategy 1: Total peat removal**

In the most comprehensive approach to lake construction, land-moving machinery is used to remove all of the residual peat from the cutaway site, creating a deep lake basin. A piped inflow is introduced from a nearby stream and the lake is flooded to a depth of 2 m or more (Fig. 6a). Lake sediments are entirely inorganic, including a mix of glacial tills, gravel, blue silty clays and shell marl. A comprehensive programme of aquatic plant and invertebrate fauna introductions are made to expedite natural recolonisation and lakes are then stocked with coarse or salmonoid fish. The lake environs are landscaped and seeded to accelerate revegetation. Being an expensive and labour-intensive process, only a limited number of lakes will be created by Bord na Móna using this strategy, designed specifically for angling purposes.

- **Strategy 2: Partial peat excavation**

In the second approach to cutaway lake creation, the bulk of the remaining peat is excavated using land-moving machinery. The removed peat is sculpted to form embankments around the lake basin and island regions in the centre of the lake, to increase habitat diversity. Drainage channels are filled in and the lake is flooded to a depth of 1-2 m. Water inputs come from a combination of precipitation, groundwater up-welling and, in some cases, a piped inflow is diverted from a nearby stream to supplement supplies (Fig. 6b). The lake substratum comprises a mixture of peat and exposed inorganic subsoils such as shell marl. Natural recolonisation of the lake environs is promoted by the planting of wild grass seed mixtures and native trees, which also increase the stability of the residual peat deposit.

- **Strategy 3: Simple flooding**

The least expensive approach to creating lakes on low-lying cutaway peatland is to simply block up the artificial drainage network. Where the cutaway site is lower than the regional water table, it will flood spontaneously from a combination of precipitation and surface drainage, typically to a depth of about 1 m. The lake substratum will consists entirely of peat (Fig. 6c), including variable amounts of *Sphagnum*, reedswamp and woody fen peat types. No post-flooding management is carried out after flooding. Bord na Móna proposes to flood increasingly large areas of cutaway peatland coming out of production in the near future using this strategy, particularly in areas around the Shannon and Suck river basins, where costly pumping is required to maintain a low water table during the later stages of peat extraction.
Cost of Cutaway Lake Creation

The financial costs associated with the various lake creation strategies are displayed in Table 2.1. This table highlights the very considerable differences in cost between the alternative lake construction strategies, arising from the contrasting levels of excavation and post-flooding management involved. In particular, Table 2.1 emphasises the economic attractiveness of Strategy 3, which enables the creation of far larger-sized water bodies with minimal financial expenditure.

![Three alternative approaches to creating lakes on cutaway peatland](image)

**Figure 6.** Three alternative approaches to creating lakes on cutaway peatland

### Table 1. The financial cost of different lake construction strategies

<table>
<thead>
<tr>
<th>Lake Creation Strategy</th>
<th>Resultant Lake Type</th>
<th>Average Size, HA (Size Ranges)</th>
<th>Cost (€ per HA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategy 1</td>
<td>Angling lake</td>
<td>4 (3-6)</td>
<td>20,000-25,000</td>
</tr>
<tr>
<td>Strategy 2</td>
<td>Shallow conservation lake</td>
<td>20 (6-60)</td>
<td>500</td>
</tr>
<tr>
<td>Strategy 3</td>
<td>Shallow conservation lake/wetland</td>
<td>40 (20-90)</td>
<td>200</td>
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</tbody>
</table>

Research Aims and Objectives

Lakes created by flooding industrial cutaway peatland are a new, essentially artificial phenomenon and no true basis in experience exists on which to predict their development. At the same time, their creation provides a unique and exciting opportunity to trace the course of development of embryonic shallow lake ecosystems as they evolve and mature. This research aimed to fulfil the following objectives, over a 3-year study period between August 2001 and September 2004:

- To investigate the water chemistry and nutrient status of experimental cutaway lakes created according to different lake creation strategies in the Irish Midlands.

- To employ phytoplankton (suspended, microscopic algae) as bio-indicators of water quality.

- To gain some understanding of the fundamental food web processes operating within cutaway lake ecosystems.

- To use the information gathered to devise guidelines for the future creation of lakes on cutaway peatlands in Ireland, which will maximise their conservation and amenity value.
Study Sites

Four experimental cutaway lakes, Finnamore, Tumduff, Turraun and Clongawny, formed the basis of this study. The four lakes are located on cutaway peatland in Co. Offaly, Ireland and were constructed according to contrasting lake creation strategies.

Location of Study Sites

The four cutaway lakes, which were monitored during the course of this study, are located in mid-west County Offaly (Fig. 7). Three of the study lakes, Finnamore, Tumduff and Turraun, are situated within the main Lough Boora Parklands complex. The fourth lake, Clongawny, is located off the R357, approximately halfway between Birr and the village of Cloghan.

Study Sites Characteristics

The following sections present, in turn, detailed descriptions of the four cutaway study lakes, Finnamore, Tumduff, Turraun and Clongawny.
I. Finnamore

The Finnamore Lakes area (N21 20) is located 16 km west of Tullamore, alongside the R357 road. The 30 ha cutaway development consists of two angling lakes and a central conservation wetland area.

The southern angling lake, Finnamore Lower Lake, which was chosen for this study, was constructed using Strategy 1, the most comprehensive approach to cutaway lake creation (Fig. 6a). The complex construction process began in summer 1996. All of the residual peat deposit at the site was removed using land-moving machinery to form a deep lake basin. The construction process exposed the underlying glacial mineral sediments, which comprised a mixture of limestone boulder tills, gravels and blue silty clays (Plate 8). A pipe was constructed at the south-west corner of the lake to introduce a flow of water from the nearby Barony Brook. The lake basin flooded rapidly, to an average depth of 1.5 m, with a maximum depth in parts of 2 m. At the north-east corner of the lake basin, an outflow pipe was laid to direct any overflow into the adjacent conservation wetland area.

A comprehensive programme of introductions, involving macroinvertebrate fauna and aquatic plants, was initiated at Finnamore to speed up natural colonisation. Today, the lake edges at Finnamore contain beds of Reed Mace (*Typha latifolia*) (Plate 7) while the lake floor contains submersed beds of stoneworts (Plate 9). The lake environs were graded, levelled and seeded and infrastructure such as fishing platforms, a car park, walkways and picnic facilities were provided. The lake was stocked in 1999 with coarse fish, such as carp, tench, rudd and bream, and is now a highly successful angling lake.

Plate 7. Finnamore lake, showing the reedbeds that are successfully recolonising the lake margins

Plate 8. Finnamore lake, with exposed blue silty clays visible in the foreground

Plate 9. Finnamore lake substratum, showing the complete removal of residual peat sediments at the site. Introduced stoneworts are visible among the stones and gravel
II. Tumduff

Tumduff (Beag) lake (N18 18') is situated in the heart of the Lough Boora Parklands. Peat harvesting ceased at Tumduff bog in 1988, and the site lay abandoned for a 7-year period. During this time, wild plants, dominated by bog cotton (*Eriophorum angustifolium*) and sedges (*Carex* spp.), spontaneously recolonised the cutaway. Creation of the 6 ha lake on a low-lying area of Tumduff cutaway commenced in summer 1995, using Strategy 2 for cutaway lake creation (Fig. 6b). During the development of the lake, a large portion of the regenerating vegetation was intentionally retained. Some of the residual peat deposit was excavated to construct a lake basin and the removed peat was used to form an island region in the centre of the lake basin (Plate 10). An underground pipe was constructed to introduce a constant flow of water from Tumduff Brook into the centre of the lake. The pipe back-floods in winter, maintaining an average water depth of 1.5 m in the lake. The lake sediment is predominantly peat, for the most part *Phragmites* reedswamp peat. The sub-peat inorganic sediments consist of glacial boulder tills and blue silty clays. In most parts of the lake, the peat depth is greater than 1 m. However, peat depths are shallower at the southern end of the lake, where some blue silty clay and boulder clay are slightly exposed.

After construction, stands of birch (*Betula* spp.) trees were planted at the site (Plate 11) and the area around the lake was reseeded with a wild grass mixture (mostly *Molinia caerulea*). An initial application of fertiliser was provided to promote revegetation and to stabilise the peat deposit at the site. These grasses were subsequently allowed to become nutrient deficient and the early vegetation gradually became replaced by a more characteristic bog flora comprising a mixture of bog cotton (*Eriophorum angustifolium*), creeping bent grass (*Agrostis stolonifera*) and various mosses. An elevated, wheelchair-accessible circular bird hide was constructed adjacent to the roadway at the south-western end of the lake (Plate 12).
III. Turraun

Turraun lake (N17 23) is situated within a 144 ha site located 3 km to the north of the R357 roadway at Boora church. The site has a long history of exploitation and, in the early 1970s, the peatfields at Turraun were the first to come out of commercial production in Ireland.

The lake at Turraun was constructed according to Strategy 2 (Fig. 6b) in October 1991. Much of the peat residue was removed using land-moving machinery and used to form embankments around the lake basin. An island region was created in the lake’s western basin. Drains were infilled with peat and marl. The rise in water levels was initially rapid, under the influence of groundwater upwelling from the underlying limestone aquifer. As precipitation became the main water source, water levels stabilised. A narrow inflow at the southern end of the lake introduces small volumes of drainage water from nearby actively milled peatfields. A podium overflow pipe was constructed in the lake’s northern embankment to prevent water levels from becoming too high.

Turraun lake is shallow, with an average water depth of 0.5 m and an estimated area of 53 ha (Plate 13). Lake sediments are predominantly *Phragmites* peat, overlying shell marl and, in turn, blue silty clay (Plates 14-15). The peat depth is variable, ranging from 0.5 m in the southern half of the lake to <1 cm in the northern basin, where exposed marl is visible.

**Plate 14.** A 1-metre sediment core from Turraun, showing the transitions between the different sediment layers

**Plate 13.** Aerial view of Turraun, shortly after the site was flooded

**Plate 15.** *Phragmites* peat at Turraun, showing the characteristic cracks and fissures on drying out.
Colonisation by macrophytes has been rapid in Turraun (Plate 16). There are large stands of emergent vegetation such as Reed mace (*Typha latifolia*) and Common Reed (*Phragmites australis*). The eastern parts of the site contain a mosaic of drier habitats, from woodlands of willow (*Salix* spp.) and birch (*Betula* spp.) to open grasslands of Arrowgrass (*Triglochin* spp.) and Moorgrass (*Molinia* spp.). Turraun is also a nationally important site for the breeding and over-wintering of many birds and has been designated as a National Nature Reserve, under the 1976 Wildlife Act, in recognition of its diverse avifaunal communities. At least 110 bird species have been recorded at Turraun, including 20 of the 29 Red Data Book species.

**IV. Clongawny**

Clongawny peatland (N07 13) is located 7 km south of Cloghan village, just off the main N62 Athlone to Birr road. There are actively milled peatlands to the southwest of the site. Large expanses of redundant cutaway peatland to the west and northwest of the lake have been planted with conifers, mostly Sitka Spruce (*Picea sitchensis*) (Plate 17). Milled peat production ceased at Clongawny between 1993 and 1994. Harvesting ceased prematurely at Clongawny, before the *Sphagnum* peat layer had been completely extracted, because the exposure of large numbers of fossil tree stumps made milling difficult. The topography of the abandoned site formed a natural depression, which partially inundated during the winter months.

The lake at Clongawny was constructed in September-October 2000 according to Strategy 3 (Fig. 6c), the simplest approach to cutaway lake creation. Very little site preparation work was carried out at Clongawny prior to flooding. The established drainage ditches at the site were infilled with peat while, at the north-western end of the lake, an outflow channel was constructed to divert surplus water into an adjacent stream (Plate 18), thus regulating water levels in the lake.
Study Sites

Over the subsequent winter months of 2000, the lake flooded spontaneously to cover a 12 ha area to an average depth of 1 m. Precipitation was the predominant water source, along with associated surface runoff and subsurface percolation from the surrounding landscape. The lake substratum at Clongawny is exclusively peat (Plate 19), comprising a mixture of *Sphagnum* and fen peats of both *Phragmites* reed and woody origin. Large amounts of exposed fossil timber remnants are evident at the site. The upper peat layer, containing varying amounts of young, poorly humified *Sphagnum* peat, is unconsolidated and has a loose, crumbly texture as a result of the last harrowing of the milling process. The pattern of the original peatfields, with intersecting drains at regular 11 m intervals, is still clearly evident (Plate 20). Loose floating rafts of fen peat, which became swollen and dislodged from the perimeter after inundation, are present at the northern end of the lake (Plate 17). The lake exhibits fluctuations of up to 10 cm in water levels in response to rainfall events or periods of dry weather and is prone to substantial wave action during times of high winds.

Natural plant recolonisation is at a very early stage in Clongawny. A non-native, invasive moss, *Campylopus introflexus*, has colonised some of the wetter drainage ditches to the south of the lake, along with the pondweed, *Potamogeton polygonifolius*. Some stands of the reed, *Phragmites australis*, have also developed at the southern end of the lake. However, the periphery of Clongawny lake is overwhelmingly barren peat (Plate 20), interspersed with small patches of pioneering Bog Cotton (*Eriophorum vaginatum*), Soft Rush (*Juncus effuses*), Ling Heather (*Calluna vulgaris*), Cross-leaved Heath (*Erica tetralix*), Gorse (*Ulex europaeus*) and birch saplings (*Betula* spp.).
**Summary of Study Site Characteristics**

The principal characteristics of the four study lakes are summarised in Table 2.

**Table 2.** Summary of the major characteristics of the four experimental Midlands cutaway lakes, Finnamore, Tumduff, Turraun and Clongawny, which formed the focus of this study

<table>
<thead>
<tr>
<th></th>
<th>Finnamore</th>
<th>Tumduff</th>
<th>Turraun</th>
<th>Clongawny</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Construction strategy</strong></td>
<td>Strategy 1</td>
<td>Strategy 2</td>
<td>Strategy 2</td>
<td>Strategy 3</td>
</tr>
<tr>
<td><strong>Construction cost, €</strong></td>
<td>120,000</td>
<td>2,400</td>
<td>22,000</td>
<td>1,800</td>
</tr>
<tr>
<td><strong>Area, ha</strong></td>
<td>4.8</td>
<td>6</td>
<td>55</td>
<td>12</td>
</tr>
<tr>
<td><strong>Mean depth, m</strong></td>
<td>1.5</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td><strong>Water supply</strong></td>
<td>Piped inflow from nearby stream</td>
<td>Piped inflow from nearby stream</td>
<td>Precipitation, spring discharges</td>
<td>Precipitation, seepage from drains, surface runoff</td>
</tr>
<tr>
<td><strong>Principal sediments</strong></td>
<td>Blue silty clay, gravel</td>
<td>Phragmites peat</td>
<td>Phragmites peat, shell marl</td>
<td>Sphagnum, woody &amp; Phragmites peat</td>
</tr>
<tr>
<td><strong>Residual peat depth, m</strong></td>
<td>0.0</td>
<td>1.0</td>
<td>0.0-0.5</td>
<td>&gt;1.5</td>
</tr>
<tr>
<td><strong>Dominant vegetation</strong></td>
<td>Typha latifolia, Chara spp., Juncus spp., Glyceria fluitans</td>
<td>Eriophorum angusfolium, Carex spp., Agrostis stolonifera</td>
<td>Carex spp., Typha latifolia, Phragmites australis</td>
<td>Phragmites australis, Juncus effusus</td>
</tr>
<tr>
<td><strong>Vegetation biomass, kg m(^{-2})</strong></td>
<td>Wet</td>
<td>263</td>
<td>57</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>71</td>
<td>21</td>
<td>38</td>
</tr>
<tr>
<td><strong>Post-flooding Management</strong></td>
<td>Environments landscaped &amp; reseeded, trees planted; invertebrates, fish &amp; charophytes introduced</td>
<td>Environments landscaped &amp; reseeded, trees planted</td>
<td>Environments landscaped &amp; reseeded, trees planted</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 2 highlights the contrasting nature of the four study lakes, in terms of their age, construction strategies, sediments, hydrological regimes and vegetation characteristics. In view of this variation, Finnamore, Tumduff, Turraun and Clongawny were considered good representatives of the spectrum of existing and potential future cutaway lakes.
Physico-Chemical Characteristics
The cutaway lakes contrasted strongly in their water chemistry characteristics (Fig. 8 and Table 3). Three of the lakes, Finnamore, Tumduff and Turraun, were alkaline, with high levels of dissolved ions, high carbonate buffering capacities and low to moderate colour levels. The fourth lake, Clongawny, was highly acidic and heavily stained, with very low levels of dissolved ions and a negligible carbonate buffering capacity. The biogeochemical characteristics of the four lakes were influenced by the depth of residual peat present, the type and degree of exposure of sub-peat inorganic sediments and the hydrological regimes at individual lakes. The presence of hardwater inflows conferred a prominent seasonality to the biogeochemistry of the alkaline lakes, Finnamore, Tumduff and Turraun, which was notably absent from Clongawny.

Table 3. Physico-chemical characteristics

<table>
<thead>
<tr>
<th></th>
<th>Finnamore</th>
<th>Tumduff</th>
<th>Turraun</th>
<th>Clongawny</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH</strong></td>
<td>8.11</td>
<td>8.08</td>
<td>8.16</td>
<td>4.64</td>
</tr>
<tr>
<td><strong>Conductivity</strong></td>
<td>429</td>
<td>365</td>
<td>299</td>
<td>72</td>
</tr>
<tr>
<td><strong>Alkalinity</strong></td>
<td>176</td>
<td>126</td>
<td>136</td>
<td>1.6</td>
</tr>
<tr>
<td><strong>Colour</strong></td>
<td>18</td>
<td>69</td>
<td>47</td>
<td>156</td>
</tr>
</tbody>
</table>

1Values shown are mean (n=54). 1 pH units; 2 μS cm⁻¹; 3 mg CaCO₃ l⁻¹; 4 mg Pt-Co. l⁻¹
Nutrient Levels

Nutrient levels in the four cutaway lakes were strongly influenced by catchment land-uses. Nitrogen levels increased in the winter in Finnamore and, to a lesser extent, in Tumduff and Turraun (Table 4 and Fig. 9), reflecting the predominant supply of inorganic nitrogen as nitrate fertiliser from agricultural sources when net rainfall was high. Co-precipitation of calcite and phosphate influenced the low phosphorus levels in Finnamore. The annual summer increase in phosphorus levels in Turraun was believed to be a consequence of phosphorus mineralisation as the exposed peat sediment became oxidized under the seasonally reduced water levels. The fourth study lake, Clongawny, experienced very substantial phosphate fertiliser runoff from adjacent coniferous forestry plantations (Plate 22). Phosphate leaching at Clongawny was accentuated by the high propensity of recently abandoned cutaway peatland to runoff and erosion, the low levels of chelating iron and carbonate ions and the paucity of regenerating vegetation at the site.

Table 4. Average nutrient levels in the cutaway lakes

<table>
<thead>
<tr>
<th></th>
<th>Finnamore</th>
<th>Tumduff</th>
<th>Turraun</th>
<th>Clongawny</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total P*</td>
<td>12.2</td>
<td>15.6</td>
<td>26.7</td>
<td>39.1</td>
</tr>
<tr>
<td>Inorganic N†</td>
<td>1,560</td>
<td>243</td>
<td>153</td>
<td>99</td>
</tr>
</tbody>
</table>

*Values shown are mean (n=54). †µg P l⁻¹; ‡µg N l⁻¹

Figure 9. Nutrient levels in the four cutaway lakes
Phytoplankton Abundances

The four cutaway lakes contrasted markedly in the abundance of phytoplankton which they contained (Fig. 5 and Table 5). Differences between lakes were closely related to the respective availabilities of nutrients, particularly phosphorus. Finnamore and Tumduff had generally low phytoplankton abundances and high species diversity and evenness, in accordance with low ambient phosphorus levels. Phytoplankton abundances were higher in Turraun, where substantial summer increases occurred, coincident with the trend in phosphorus concentrations. Increased summer phytoplankton abundance in Turraun was accompanied by dips in phytoplankton species diversity and evenness. Clongawny exhibited a very substantial increase in phytoplankton standing crop over the 3-year study (Fig. 10). Chlorophyll-a levels were defined as being hypereutrophic\(^{11}\) between November ‘02 and May ‘04. This surge in phytoplankton production was stimulated by the runoff of phosphate from nearby commercial forests. There were coincident declines in phytoplankton species diversity and evenness at Clongawny (Fig. 10). Collectively, these findings reinforce the crucial influence of catchment land-uses on water quality in cutaway lakes.

\[\text{Table 5. Phytoplankton abundance, diversity and evenness}\]

<table>
<thead>
<tr>
<th></th>
<th>Finnamore</th>
<th>Tumduff</th>
<th>Turraun</th>
<th>Clongawny</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll-a (^1)</td>
<td>5.2</td>
<td>3.3</td>
<td>12.7</td>
<td>52.5</td>
</tr>
<tr>
<td>Biovolume (^2)</td>
<td>1,101</td>
<td>608</td>
<td>3,057</td>
<td>33,641</td>
</tr>
<tr>
<td>Sp. diversity (^3)</td>
<td>0.74</td>
<td>0.63</td>
<td>0.62</td>
<td>0.35</td>
</tr>
<tr>
<td>Sp. evenness (^4)</td>
<td>0.67</td>
<td>0.65</td>
<td>0.57</td>
<td>0.45</td>
</tr>
</tbody>
</table>

\(^1\) Values shown are mean (n=54). \(^2\) µg Chl-a l\(^{-1}\); \(^3\) mm\(^3\) m\(^{-3}\); \(^4\) D (Simpson Index); \(^4\) E (Evenness)

Figure 10. Phytoplankton abundances, diversity and evenness in the cutaway lakes
Phytoplankton Composition

The phytoplankton populations in Finnamore, Tumduff and Turraun were dominated by two main groups, green algae (chlorophytes) and diatoms (Fig. 11). However, Turraun lake exhibited summer increases in cyanobacteria (blue-green ‘algae’). Increased phosphorus and concurrently inflated phytoplankton production in Clongawny was associated with a marked transformation in phytoplankton compositional dominance, which shifted from an earlier prevalence of dinoflagellates, to a near monospecific bloom of small, unicellular chlorophytes.

Figure 11. Phytoplankton taxonomic composition in the cutaway lakes
Chlorophytes and Diatoms

The phytoplankton flora in the 3 alkaline lakes, Finnamore, Tumduff and Turraun, was generally co-dominated by a diverse range of diatom and chlorophyte (green algae) species.

A rich diatom flora is indicative of high levels of silica in the water, a nutrient which is essential for the construction of the siliceous diatom cell wall.

Cyanobacteria in Turraun

Moderate, to large, populations of colonial cyanobacteria developed in Turraun in summertime, in response to the seasonally elevated levels of phosphorus in the lake.

Chlorophytes in Finnamore, Tumduff and Turraun included unicellular, filamentous and colonial forms.

Chlorophyte bloom in Clongawny

Acid-tolerant dinoflagellates, such as Peridinium umbonatum, were very common in Clongawny lake during 2001 and early-2002. As the phytoplankton standing crop increased in response to phosphate runoff, the phytoplankton flora became overwhelmingly dominated by very small, unicellular and highly buoyant chlorophytes, such as Cosmarium pygmaeum and Chlorella spp.
What nutrient limited phytoplankton growth in the cutaway lakes?

A series of nutrient enrichment bioassays was conducted in order to assess the impact of changes in the availability of phosphorus and nitrogen on phytoplankton production in the cutaway lake ecosystems (Plate 23). Determining the key nutrient(s) which regulate phytoplankton growth in cutaway lakes has important implications for overall lake water quality, since phytoplankton production influences a variety of other properties such as water clarity, dissolved oxygen availability and the development of higher trophic levels in the food chain.

Plate 23. Nutrient enrichment bioassays involved adding various concentrations of nitrogen and phosphorus to subsamples of lake water, and measuring phytoplankton responses (as chlorophyll-a) after a 2-week incubation outdoors, at ambient temperate and light conditions

The results of the nutrient enrichment bioassays, together with the longer-term nutrient data from the lake monitoring programme, indicated that the phytoplankton populations in the four study sites underwent transitions between phosphorus and nitrogen limitation. While phosphorus was the primary limiting nutrient, nitrogen-limitation was also detected in all four cutaway lakes. Finnamore, Tumduff and Turraun all experienced varying degrees of nitrogen limitation in summer, as inorganic nitrogen supplies in these lakes were depleted in response to phytoplankton growth and reduced inflow of nitrate from the catchment. As Clongawny became increasingly eutrophic in response to phosphate runoff from adjacent forestry plantations, nitrogen concentrations were reduced to undetectable levels. As a consequence of this artificial enrichment, phytoplankton communities in Clongawny experienced secondary nitrogen limitation for much of 2003 and 2004 [12].

Results emphasised the often-neglected role of nitrogen, as well as phosphorus, in controlling freshwater eutrophication.

Phosphate Regeneration Mechanisms

Part of this study investigated the potential for the regeneration of bioavailable phosphate from recalcitrant, complex organic complexes in cutaway lakes by 3 alternative release mechanisms:

- Enzymatic hydrolysis (P-EH)
- UV-induced photolysis (P-UV)
- Combined UV- and enzymatic hydrolysis (P-UVEH)

Results showed that phosphate can potentially be released by each of the 3 regeneration mechanisms studied. P-EH resulted in an average phosphate increase of 2.6 µg l⁻¹; P-UV supplemented phosphate levels by 0.9 µg l⁻¹, while P-UVEH increased phosphate levels by 2.3 µg l⁻¹.

Collectively, these results indicate that the regeneration of bioavailable phosphate from the large internal organic phosphorus pools may partly account for the development of nitrogen limitation in the cutaway lakes, by maintaining a constant supply of readily available phosphorus to the phytoplankton.

Food Web Dynamics

A focus of this research was to investigate the relative importance of bottom-up (nutrient) versus top-down (grazer) control in regulating phytoplankton populations in cutaway lakes. To this end, the zooplankton communities in Turraun and Clongawny lakes were surveyed between June and September 2003. For comparative purposes, the zooplankton communities in a cutaway lake and in an intact blanket bog lake at Bellacorick bog in northwest Co. Mayo were also examined [16].

Results indicated that the lakes studied contained high levels of invertebrate predation on herbivorous zooplankton species and, consequently, reduced grazing pressure on the phytoplankton populations. The elevated importance of invertebrate predation in the lakes reflected the absence of higher predators, such as piscivorous fish, from these systems. The predatory cladoceran, *Polyphemus pediculus* (Plate 24), was present in large numbers in both the natural and cutaway bog lakes at Bellacorick, while a predatory cyclopid copepod which is rare to Ireland, *Tropocyclops prasinus* (Plate 25), was very abundant in Clongawny lake. The high number of predatory cyclopid copepods in Clongawny was believed to have influenced the low numbers of herbivores in this lake, relative to the very abundant phytoplankton food-base. The cladoceran community was dominated by small-bodied detritivorous chydorids, while highly efficient grazers, such as daphnids, were scarce. The absence of an effective grazing population in Clongawny confirmed predictions that phytoplankton productivity in the lake is strongly bottom-up (i.e. nutrient) controlled. Very low overall zooplankton abundances in Turraun supported conclusions from other studies [14, 15] that this lake has a rich, well-developed, predatory macroinvertebrate population.

It appears that two inter-related factors were crucial in influencing the development of rudimentary food chains in cutaway lake systems: (i) the lake creation strategy, and (ii) age. The lake creation strategy used in the development of new lakes was crucial, both in determining the habitat diversity and physico-chemical environment, and in influencing the re-vegetation of cutaway sites by higher plants. These characteristics, in turn, impacted on the diversity and richness of the planktonic floral and faunal communities that developed in the new lakes. Age was found to be an important factor, directly increasing the length of time available for the invasion of new phytoplankton, zooplankton and macroinvertebrate species, and indirectly influencing important site characteristics, such as the sediments, food availability, vegetation cover and plant species richness.
Major Conclusions

The following major conclusions can be drawn from this research:

1. **The physico-chemical environment in cutaway lakes** is primarily determined by the lake creation strategy used, which affects two key characteristics: (i) the sediments, and (ii) the hydrological regime. Hardwater inflows, coupled with sediments comprising a mixture of minerotrophic fen peats and exposed inorganic, calcareous subsoils, such as those occurring in Finnamore, Tumduff and Turaun, produce alkaline, base-rich lakes containing low to moderate levels of colour. Lakes created according to Strategy 3, such as Clongawny, contrast strongly with previous cutaway lake models, in being very acidic, highly coloured and base poor, with a negligible carbonate buffering capacity.

2. **Nutrient levels** in cutaway lakes are influenced strongly by catchment land-uses. Lakes containing discrete inflows, either via inflow pipes or groundwater discharge, such as Finnamore, Tumduff and Turaun, typically exhibit a marked seasonality in inorganic nitrogen levels. Elevated nitrate levels in winter in such lakes reflect nitrate runoff from agricultural land. Elevated phosphorus levels in summertime in Turaun are believed to reflect phosphate mineralisation in the seasonally exposed lake sediments. Lakes created using Strategy 3 are particularly susceptible to eutrophication arising from nutrient leaching, for example from adjoining forestry. This vulnerability arises from the poor chelating capacity of the peat sediment, the high erosion and runoff risk of the bare, unconsolidated peat sediments, and the absence of buffering macrophytes at these lakes. These findings emphasise the risk of external nutrient enrichment for cutaway lakes created using Strategy 3.

3. **Phytoplankton abundance** in cutaway lakes is determined primarily by nutrient levels, and increases proportionately with increasing ambient phosphorus availability. Phytoplankton species diversity in cutaway lakes is influenced by a combination of factors, including silica and light availability. Lakes created by Strategy 3, such as Clongawny, can be expected to be overwhelmingly dominated by a small number of phytoplankton species physiologically adapted to the low light environment, low pH and high phosphorus availability.

[16-17]
4 Seasonal nitrogen limitation of phytoplankton productivity is common in cutaway lakes. Lakes in agricultural catchments, such as Finnamore, Tumduff and Turraun, have a propensity to become seasonally nitrogen-limited in summertime as inflows recede, reflecting the importance of external sources in the supply of inorganic nitrogen to cutaway lakes. Lakes in receipt of phosphate runoff from commercial forestry plantations may evolve secondary nitrogen limitation, as inorganic nitrogen supplies are rapidly depleted by the inflated phytoplankton population. However, cutaway lakes are not prone to developing populations of heterocystous nitrogen-fixing cyanobacteria, despite the occurrence of seasonal, or more sustained, nitrogen limitation. Limited studies indicate that phosphate regeneration mechanisms may play a significant role in maintaining a bioavailable phosphate supply in cutaway lakes, regardless of their trophic status, thereby contributing to the development of nitrogen limitation in cutaway lakes.

5 Newly established cutaway lakes appear to support a high level of microinvertebrate predation on herbivorous zooplankton populations and, consequently, reduced top-down regulation of phytoplankton growth by grazers. Longer established lakes contain more evolved foodwebs, involving a proportionately higher level of macroinvertebrate predation. Two factors are important in influencing the development of a rich and diverse biological community in cutaway lakes: (i) age, which determines the length of time available for colonisation of new lakes, and (ii) lake creation strategy, which influences the sediment characteristics, water chemistry, level of habitat diversity and extent of revegetation.

6 Industrial peat harvesting of Midlands raised bogs was, inevitably, associated with the destruction of unique ecosystems and loss of their associated biodiversity. Lake and wetland creation on redundant cutaway peatland provides an opportunity to redress this balance. It is clear, from the current study, that the strategy adopted for lake creation will impact strongly on future biodiversity at all trophic levels. Data indicate that Strategy 3, the most recently adopted and most cost-effective approach to lake creation, will support far lower biodiversity than the previous approaches to lake creation (Strategies 1 and 2), and that such lakes will be highly vulnerable to eutrophication arising from nutrient runoff from the catchment. While highly successful, Strategy 1, involving the expensive creation of angling lakes, will be limited in its future application on the basis of economics. Strategy 2, however, was found to promote comparably high levels of floral and faunal species diversity as Strategy 1, at far lower expenditure. This strategy, by which Tumduff and Turraun lakes were developed, appears to be the preferential model for future cutaway lake creation, with respect to biodiversity promotion and conservation value.

Recommendations for Future Cutaway Lake Creation

1 Revegetation of cutaway sites
This study clearly highlighted the direct and indirect benefits of revegetating cutaway peatland designated for lake creation. Higher vegetation:-(i) increases the sediment stability of the peripheral cutaway and of the lake substrata, reducing water column turbidity and nutrient recycling from the bottom sediments; (ii) filters nutrient runoff from the catchment area, thus reducing the nutrient loading imposed on water-bodies; (iii) competes with phytoplankton for nutrients and other resources within lakes, thus restricting phytoplankton growth; and (iv) increases habitat, refuge and food availability for recolonising invertebrates, thereby increasing phytoplankton losses by grazing. The natural recolonisation by plants of cutaway peatland intended for lake creation should be assisted and expedited by active management. Creating small changes in the surface elevation or texture of bare, uniform cutaway peatfields increases the variability of the near-surface microclimate, encouraging natural plant establishment. As cutaway peatland usually lacks a viable seed bank, planting an initial cover of vascular plants, such as bog cotton (Eriophorum anguslifolium) and sedges (Carex spp), for the first 3-5 years would provide valuable protection that could prevent wind erosion, surface drying and young plant desiccation. Initial fertilization may be useful to assist the establishment of this preliminary vegetation, with particular attention to the balance between phosphorus and nitrogen. The success of this approach was demonstrated at Tumduff.

2 Maximisation of physical habitat diversity
Lakes should be designed with an irregular shoreline, involving bays, inlets and island regions. Lake shores should be gently sloping, to encourage the establishment of littoral aquatic plants. An exposure of inorganic subsoils is desirable in order to increase sediment variability. Collectively, these measures would provide a diversity of microhabitats within individual lakes, which, in turn, would promote increased biological diversity and species richness.

3 Hydrological flow-through
An active hydrological flow-through at cutaway lakes decreases the hydrological residence time, thus reducing the level of sediment-water interaction. This measure would minimise nutrient recycling from the sediments. Diverting a flow of water from a natural stream would also expedite natural recolonisation by microinvertebrates and macroinvertebrates. Moreover, a piped inflow, providing a constant supply of water to cutaway lakes, would help to stabilise water levels, reducing the desiccation of peat sediments in summertime and consequent inorganic nutrient mineralisation.
Conclusions & Recommendations

4 Integrated planning

A holistic approach, which balances economic, practical and technical concerns, needs to be adopted, if the biological diversity of cutaway sites is to be maximised. In particular, vegetation buffer zones should be established between existing, intensively cultivated terrestrial areas and newly created, or planned, aquatic systems. When designating future post-harvesting uses of cutaway peatland, the vulnerability of soils to nutrient (in particular phosphorus) loss in runoff should be identified. By identifying cutaway areas with "strong" nutrient barrier capacities and "low-barrier" areas, based on the dual characteristics of soil sorption properties and extent of revegetation, future land-uses can be designated in an appropriate, site-specific manner. In low-lying cutaway areas, situated adjacent to commercial forestry plantations, the potential of creating shallow wetlands and reedbeds, instead of lakes (>1 m depth), should be examined, in view of the very high nutrient-removal capacity of such systems.

5 Long-term monitoring

In view of the considerable timescale involved in ecosystem establishment and stabilisation, it is essential that monitoring of the existing cutaway lakes continues, so that long-term trends can be assessed. Continued attention should be paid to assessing the development of phyto- and zooplankton communities in lakes developed according to alternative strategies, in order to comparatively assess the development of stabilised food-webs in contrasting cutaway lake types. Given current proposals to develop lake and wetland systems on 20,000 ha of the Midlands cutaway peatland, such long-term monitoring is essential in order to provide an informed blueprint for future lake creation that will maximise the conservation and biodiversity value of these new resources.
Related Reading Material


Relevant Websites

Bord na Móna: www.bnm.ie
Lough Boora Parklands: www.loughbooraparklands.com
Irish Peatland Conservation Council: www.ipcc.ie
International Peat Society: www.peatsoociety.org
The One

Green, blue, yellow and red
God is down in the swamps and marshes
Sensational as April and almost incredible
the flowering of our catharsis.
A humble scene in a backward place
Where no one important ever looked
The raving flowers looked up in the face
Of the One and the Endless,
the Mind that has balked the profoundest of mortals.
A primrose, a violet, a violent wild iris
But mostly anonymous performers
Yet an important occasion as the Muse at her toilet
Prepared to inform the local farmers
That beautiful, beautiful, beautiful God was breathing
His love by a cut-away bog.

Patrick Kavanagh
Lake Creation on Cutaway Peatlands in Ireland